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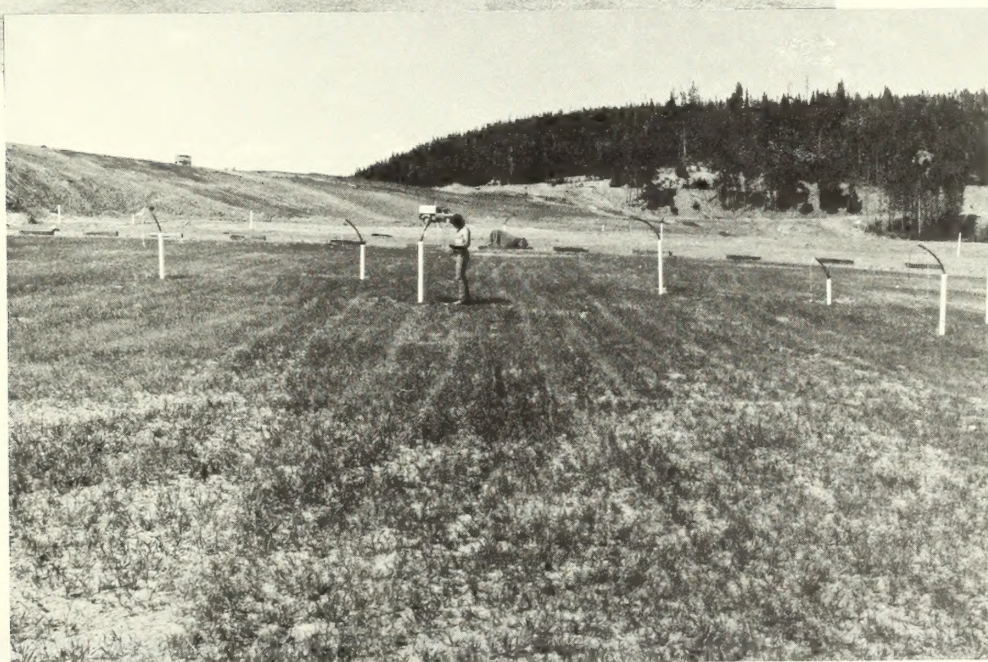
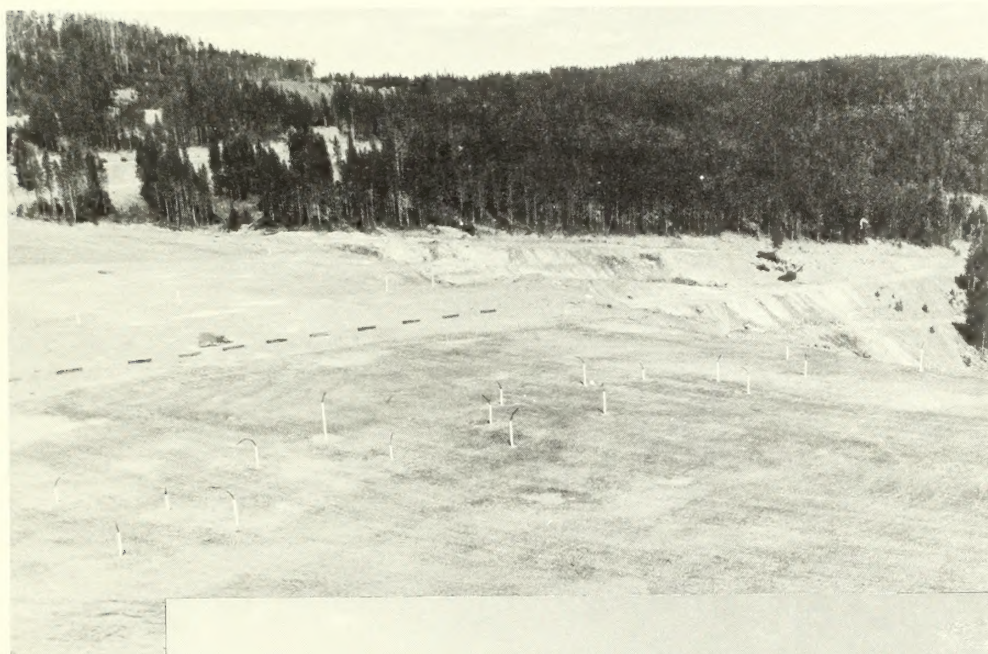
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ACID MINE WASTE REVEGETATION: INFLUENCE ON SOIL-WATER QUALITY

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RESEARCH SUMMARY

The paper presents the results of a 5-year study of the soil-water ionic concentrations of copper, iron, and sulfate. Ceramic soil-water samplers were installed in an acid producing overburden waste dump. A portion of the waste material was treated with lime, topsoil, and fertilizer, and was reseeded to a heavy grass stand. Another portion of the waste material was untreated. For this acid mine drainage situation two conclusions are drawn: (1) both the revegetated and untreated areas show decreasing soil-water ionic concentrations of copper, iron, and sulfate; and (2) the revegetation procedures have not changed the soil-water ionic concentrations of copper, iron, and sulfate as compared to no surface treatment.

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INTRODUCTION

Abatement of acid drainage arising from the oxidation of sulfide mineral mining wastes stored on the land surface has probably never been accomplished on an operational scale, short of completely submerging the waste under water. Submergence is an effective but limited treatment. Effective abatement programs are noticeably absent from the acid mine drainage literature. However, this is not to imply that some abatement has not been realized in the past. Where abatement has been realized, it is more traceable to nature and time than to any conscious act of people.

Lime, topsoil covers, and vegetation have been suggested as a means of reducing the acid mine drainage (AMD) problem. The efficacy of vegetation as an erosion control agent cannot be doubted. Vegetation can break the cycle of erosion continually exposing new unoxidized sulfides. It has also been suggested that topsoil and vegetation might create a sufficient oxygen demand in the root zone to reduce sulfide mineral oxidation (Brant and others 1971), but the realization of this is not documented.

This paper presents the results of a 5-year study of the soil-water ionic concentrations of copper, iron, and sulfate — common components of AMD in the western United States. The results of the study highlight the intractability of the problem.

METHODS

The study site is on the Blackbird copper-cobalt mine on the Salmon National Forest near Salmon, Idaho. The study site and mine property have been described by Farmer, Richardson, and Brown (1976). The overburden waste pile at the study site contains approximately 1.1 million cubic yards (1 million cubic meters); the maximum fill depth is estimated to be 75 ft (23 m); the elevation of the site is 7,760 ft (2 365 m). The waste pile is about 25 years old.

During May and June of 1974, some 45 access holes were drilled to depths varying from 4 to 61 ft (1.2 to 18.6 m). These holes were spread along two line transects 200 ft (61 m) apart. Each transect was about 240 ft (73 m) long on nearly level ground. Porous ceramic cup soil-water samplers were installed in each hole. In holes more than 10 ft (3 m) deep the samplers were constructed after

the suggestions of Wood (1973). Prior to installation, each ceramic cup was washed at least three times with 1N HCL and rinsed with deionized water.

Shortly after the soil-water samplers were installed, the surface 8 to 10 inches (200 to 250 mm) of overburden was removed from one of the line transects. This shallow excavation extended the full length of the transect, 240 ft (73 m), for about 100 ft (30 m) to either side of the transect. This excavation was replaced with local forest topsoil and shallow subsoils. The operation resulted in an area topsoiled with 8 to 10 inches (200 to 250 mm) of native soils with no change in the surface elevation.

During topsoiling, 1,800 lb/acre (2 030 kg/ha) of burnt lime (CaO) was incorporated into the topsoil. The topsoiled area sat fallow during the summer. In early October 1974, an additional 4,000 lb/acre (4 470 kg/ha) of burnt lime was incorporated into the topsoil. The topsoiled area was heavily reseeded to a mixture of native and introduced grasses, was fertilized with 1,300 lb/acre (1 420 kg/ha) of liquid 10-34-0, and mulched with 2,700 lb/acre (3 050 kg/ha) of wood fiber. In July 1975, the topsoiled area was refertilized with 225 lb/acre (254 kg/ha) of a slow release 26-3-5 fertilizer. In September 1975, the revegetated area was relimed with 4,500 lb/acre (5 080 kg/ha) of agricultural crushed limestone.

These operations resulted in two line transects of soil-water samplers. One transect was untreated and completely devoid of vegetation; the waste dump had never revegetated naturally. The other transect, for a width of about 200 ft (61 m), was topsoiled, limed, and revegetated to a heavy stand of grass, about 2,500 lb/acre (2 800 kg/ha) air-dry weight in the second growing season.

The soil-water samplers were evacuated with a vacuum pump driven by a one-third horsepower electric motor. A portable electric generator supplied electricity. Between sample dates the samplers were left under vacuum. They were also reevacuated 24 hours prior to the collection of the soil-water sample. Sample size varied considerably, both spatially and temporally, from a few milliliters to nearly a liter. Regardless of sample size, the entire sample was removed on each sample date.

Soil-water samples were stored in clean polypropylene 250 ml bottles. The samples were not acidified, but were refrigerated and transported back to the laboratory. Analyses for copper, total

iron, and sulfate were performed in the Soil and Water Analysis Laboratory of Utah State University, Logan, Utah.

For reasons mostly unknown, 13 of the installed samplers ceased to function during the study period. The results of the remaining 32 are reported here. The data were screened to assure that each soil-water sampler used in the analysis was represented in both the 1974-75 and 1977-79 sample periods.

A lot of variation exists within the data; the data may also be biased due to the differential exchange properties of the ceramic cups (Grover and Lamborn 1979; Severson and Grigal 1976; Hansen and Harris 1975). Probable sources of data variation include variable intake rates of the ceramic cups, a long extraction time (Severson and Grigal 1976), a nonhomogenous soil solution, and the phenomenon whereby ions in a soil solution do not vary inversely with soil-water content (Reitemeier 1946).

Although the data are variable, there are 491 observations, including ionic concentrations of copper, iron, and sulfate.

Multivariate cluster analysis operates under less restrictive assumptions than some other statistical techniques — analysis of variance for instance (Davis 1973). This is probably advantageous in field problems involving complex and interacting processes that are impossible to isolate and study individually. This is the case in the present instance, where it is necessary to sort out, *a posteriori*, the influence of revegetation.

The data contain 491 samples from 32 sample tubes; 21 tubes on the revegetated area and 11 tubes on the untreated (bare) area. The samplers on the revegetated area average 21 ft (6.4 m) deep, with a range from 4 to 61 ft (1.2 to 18.6 m). The samplers on the untreated area averaged 16 ft (4.9 m) deep, with a range from 4 to 44 ft (1.2 to 13.4 m). The data were not separated by depth.¹

Sampling dates were:

7/25/74	6/15/77
8/29/74	9/1/77
3/12/75	10/19/77
5/29/75	6/14/78
6/25/75	10/14/78
7/17/75	6/14/79

¹An analysis of variance test on both the treated and untreated areas suggests that there is no difference in the data due to depth, probability = 0.9.

RESULTS

On-site precipitation was measured with an aluminum standpipe storage gage fitted with an Alter windshield. For the water years (Oct. 1 to Sept. 30) 1975, 1976, 1977, and 1978, the precipitation amounts were 25.5 inches (648 mm), 20 inches (508 mm), 23.5 inches (597 mm), and 16 inches (406 mm), respectively. There are no long-term precipitation records available for this site, but the 4-year measured precipitation is probably less than a 30-year average.

Considering the basic statistics of the samples, number of observations, mean, standard deviation, and range, there does not appear to be any difference in the ionic concentrations of the soil water due to revegetation (table 1). However, both the revegetated and untreated areas appear as though some improvement in water quality has taken place over time. At least the sample ionic means show some reduction. However, the large sample standard deviations increase the uncertainty of any statistical inference purporting to show differences between sample means.

Cluster Analysis

Hierarchical cluster analysis was performed at the computer center of Utah State University, Logan (Marshall and Romesburg, undated). The data for each ion were standardized by subtracting the mean from the observed value and dividing the result by the standard deviation. This procedure ensures that each value in the data matrix is weighted equally (Sneath and Sokal 1973). The resemblance coefficient was the m -space Euclidian distance, d_{ij} , which is a measure of dissimilarity,

$$d_{ij} = \left[\left(\sum_{k=1}^m (X_{ik} - X_{jk})^2 \right) / m \right]^{1/2}$$

where X_{ik} denotes the k th variable measured on i th object. In all, m variables are measured for each object and d_{ij} is the distance between the i th and j th objects. As you would expect, a small distance indicates that the objects are similar while a large distance indicates dissimilarity. The m -space Euclidian distance ranges from zero to infinity. The clustering technique used was the unweighted pair-group method using arithmetic averages (UPGMA).

CLUSTER ANALYSIS
74 - 75

REVEGETATED AND UNTREATED AREAS

U - Untreated (11 Tubes)

R - Revegetated (21 Tubes)

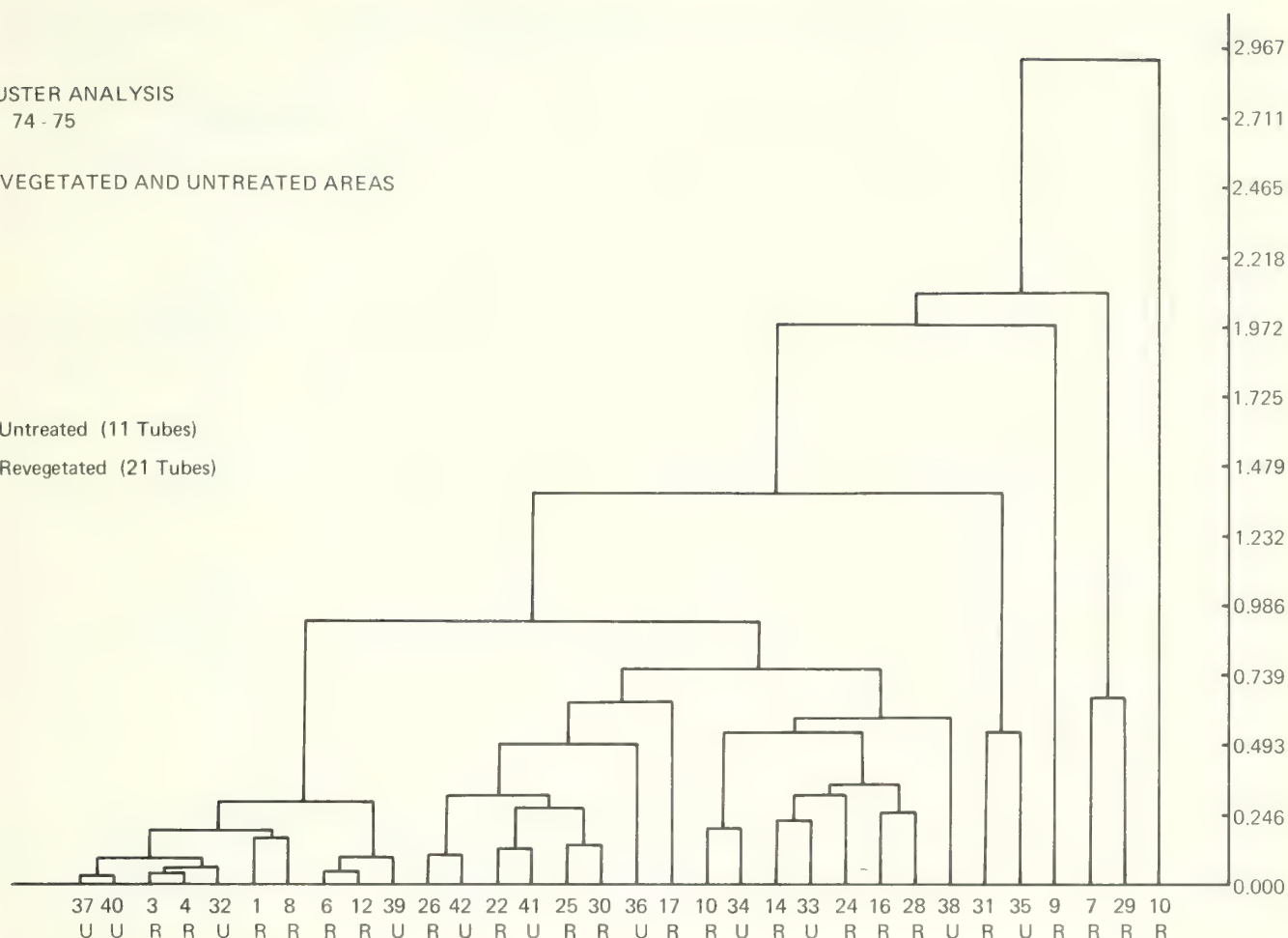


Figure 1.—Dendrogram of soil-water samplers on the revegetated and untreated areas, 1974-75. Cophenetic correlation = 0.92.

For these data the “objects” were the ceramic cup soil-water samplers and the variable for each object was the mean ionic concentration of copper, iron, and sulfate. The analysis was to determine which of the soil-water samplers are similar and which dissimilar. This information can be visualized in dendrograms, or trees. A way to conceptualize a dendrogram is to imagine how objects look as one gets progressively farther away from them. Up close, $d_{ij} = 0$, every sampler is seen individually. As the distance increases, individual samplers become progressively more difficult to discern and the observer sees only groups of samplers. Finally, at the greatest distance, no individuals are seen, and only one large group comprising the entire set of objects can be discerned. This distance abstraction is evident in the following dendrograms.

Revegetated vs. Untreated Areas, 1974-75

The dendrogram of soil-water samplers on the revegetated and untreated areas for this period does not indicate strong similarities between samplers within either area (fig. 1). The decision about where to cut the tree is subjective and is analogous to distance abstraction. If we cut the tree at about one-fourth of the total Euclidian distance, we divide the samplers into seven groups of similar soil-water samplers (table 2).

In the total set of samplers, 21 are on the revegetated area and 11 on the untreated area. The distribution of the samplers (table 2) does not suggest any strong degree of grouping within either the revegetated or untreated area.

Table 1.—The number of samples, mean, standard deviation, and range for copper, iron, and sulfate in the soil water samples, mg/liter

	Revegetated area		Untreated area	
	1974-75	1977-79	1974-75	1977-79
Copper, Cu	n=57 $\bar{x}$ =3.43 S.d. =10.13 range=0 to 60.1	n=53 $\bar{x}$ =2.30 S.d.=7.73 range=0 to 44.2	n=31 $\bar{x}$ =2.67 S.d =9.42 range=0 to 52.0	n=25 $\bar{x}$ =0.72 S.d.=1.65 range=0 to 7.8
Total iron, Fe	N=57 $\bar{x}$ =0.41 S.d.=0.47 range=0 to 1.9	n=53 $\bar{x}$ =0.11 S.d.=0.22 range=0 to 1.3	n=35 $\bar{x}$ =0.60 S.d.=0.62 range=0 to 2.6	n=26 $\bar{x}$ =0.16 S.d.=0.47 range=0 to 2.4
Sulfate, SO ₄	n=52 $\bar{x}$ =585.75 S.d.=486.56 range=19 to 1,477	n=50 $\bar{x}$ =271.08 S.d.=292.77 range=5 to 1,040	n=27 $\bar{x}$ =498.41 S.d.=459.89 range=10 to 1,462	n=25 $\bar{x}$ =220.41 S.d.=233.49 range=<1 to 745

Table 2.—Sampler groups resulting if the dendrogram is cut at a distance of 0.75

Group	Number of samplers	Number in revegetated area	Number in untreated area
1	10	6	4
2	8	5	3
3	8	5	3
4	2	1	1
5	1	1	—
6	2	2	—
7	1	1	—

Based on the evidence in figure 1 and table 1, we conclude there probably was no difference in the soil-water quality underlying the revegetated and untreated areas in this sample period.

Revegetated vs. Untreated Areas, 1977-79

The dendrogram for this sample period on the revegetated and untreated areas indicates no strong similarities within either area (fig. 2). Where-

ever the tree is cut, there is no convincing grouping of samplers within the revegetated or untreated areas.

Based on the evidence in table 1 and figure 2, we conclude there were no differences in the soil-water quality underlying the revegetated or untreated areas in this period.

CLUSTER ANALYSIS

77-79

REVEGETATED AND UNTREATED AREAS

U - Untreated (11 Tubes)

R - Revegetated (21 Tubes)

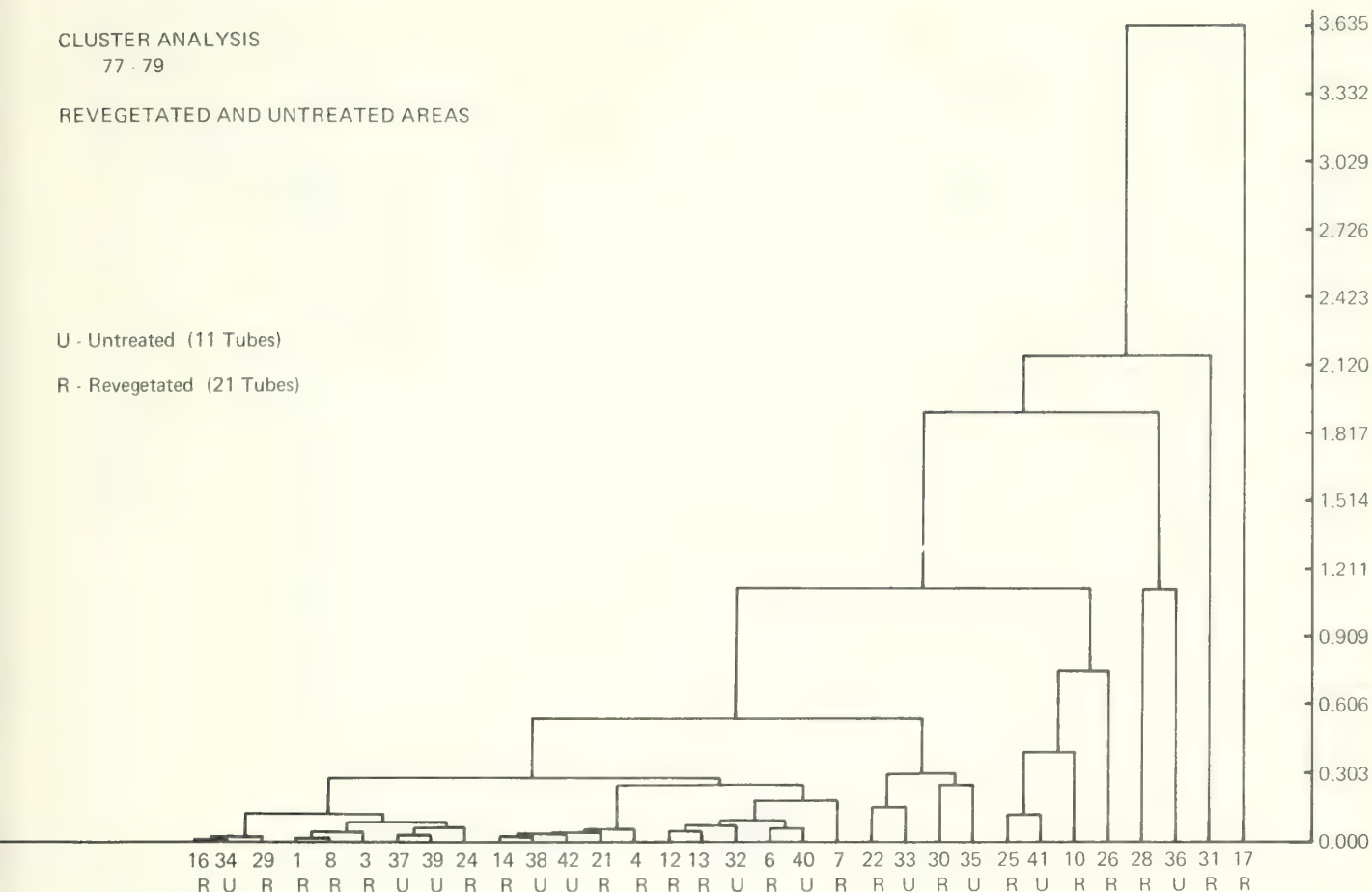


Figure 2.—Dendrogram of soil-water samplers on the revegetated and untreated areas, 1977-79. Cophenetic correlation = 0.95.

Untreated 1974-75 vs. Untreated 1977-79

The dendrogram using the samplers on the untreated area only for both sample periods indicates a tendency for sampler grouping by sampling period (fig. 3).

Since the same samplers are shown twice in figure 3, once for 1974-75, once for 1977-79, an even split within dendrogram groups by years would indicate no difference in the water quality from 1974-75 to 1977-79. However, that is probably not the case. If the tree is cut at 0.70, seven

groups of similar soil-water quality emerge (table 3.) Most of the 1977-79 samplers are contained within the first group and are represented twice as often as would happen by chance. Groups 4, 5, 6, and 7 contain more of the 1974-75 samplers than would be expected by chance. In this case there is a tendency for 1974-75 results to group, and for 1977-79 results to group. In other words, the 1977-79 samplers are more similar to each other than they are to the 1974-75 samplers.

Based on the evidence in figure 3 and table 1, we conclude there is a difference in the soil-water quality from 1974-75 to 1977-79. The concentration of copper, iron, and sulfate has decreased.

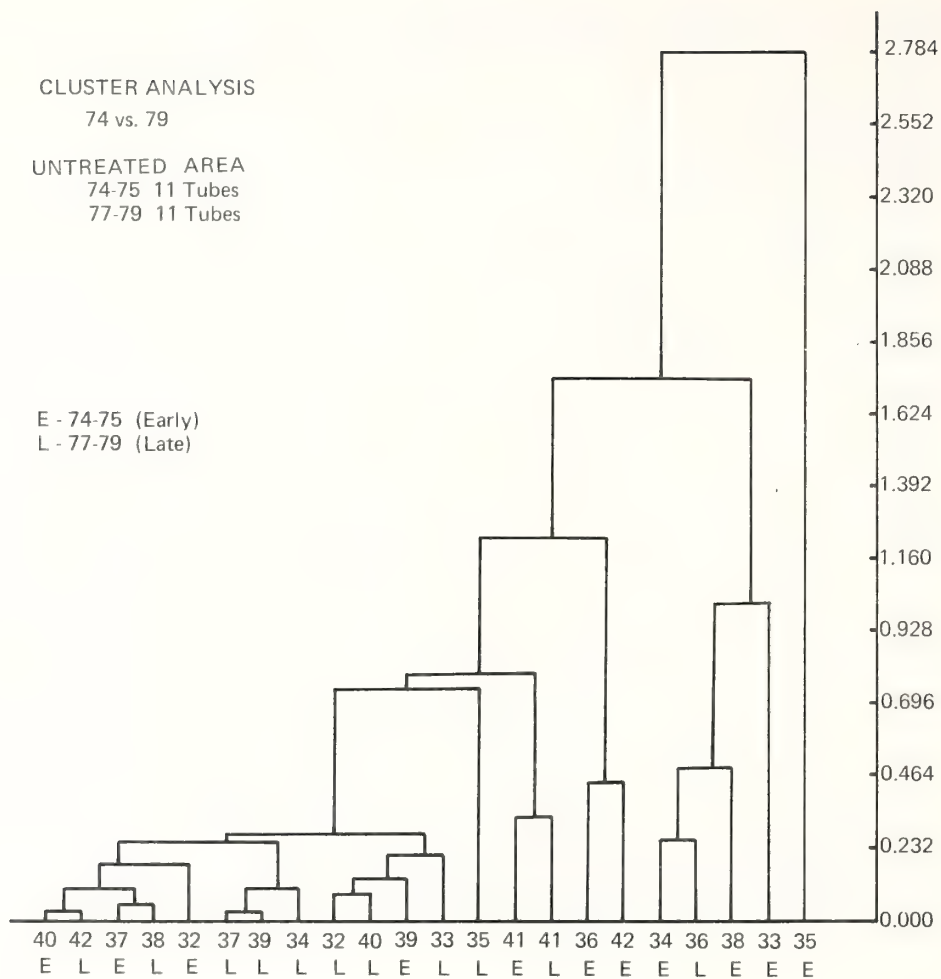


Figure 3.—Dendrogram of soil-water samplers on the untreated area only, 1974-75 and 1977-79.
Cophenetic correlation = 0.88.

Table 3.—Sampler groups resulting when the dendrogram in figure 3 is
cut at a distance of 0.70

Group	Number of samplers	Untreated	
		1974-75	1977-79
1	12	4	8
2	1	—	1
3	2	1	1
4	2	2	—
5	3	2	1
6	1	1	—
7	1	1	—

CLUSTER ANALYSIS

74 vs. 79

REVEGETATED AREA

74-75 21 Tubes

77-79 21 Tubes

E - 74-75 (Early)

L - 77-79 (Late)

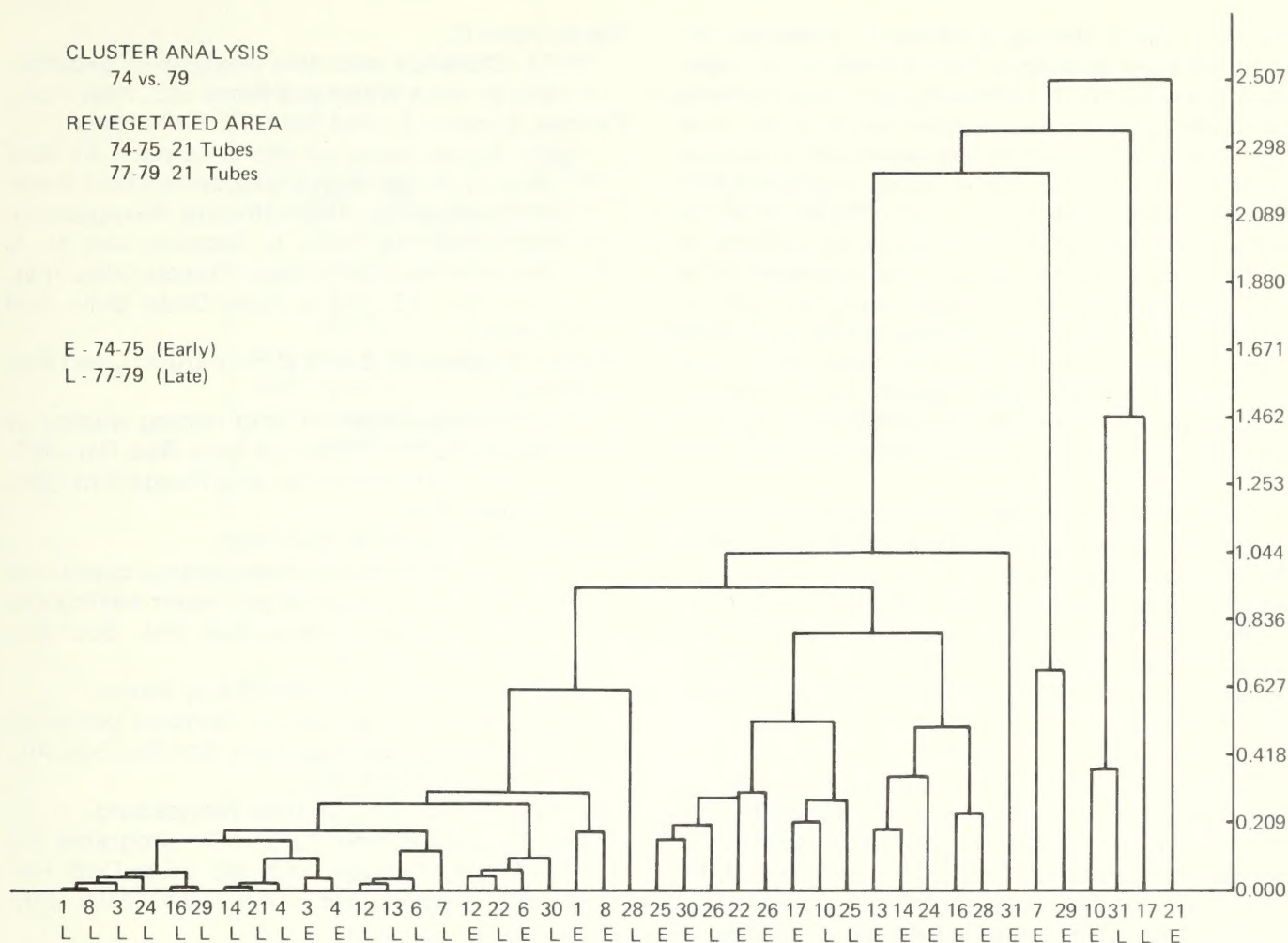


Figure 4.—Dendrogram of soil-water samplers on the revegetated area only 1974-75 and 1977-79. Cophenetic correlation = 0.93.

Revegetated 1974-75 vs. Revegetated 1977-79

The dendrogram for the revegetated area in 1974-75 and 1977-79 (fig. 4) exhibits a tendency similar to that of the untreated area. That is, the 1974-75 samples tend to group, as do the 1977-79 samples.

We conclude that there has been some real change in water quality on the revegetated area over time; the concentration of copper, iron, and sulfate has decreased.

CONCLUSIONS AND DISCUSSION

On the basis of the data (table 1) and cluster analysis results, we draw two conclusions regard-

ing the influence of revegetation on water quality in this acid mine waste situation:

1. Both the revegetated and untreated areas show decreasing soil-water ionic concentrations of copper, iron, and sulfate over the 1974-79 study.
2. The revegetation procedures, including top-soiling and liming and subsequent vegetative growth, have not changed the soil-water ionic concentrations of copper, iron, and sulfate as compared to no surface treatment.

Regarding the first conclusion, what is the probable cause of the decreasing amounts of soluble iron, copper, and sulfate in the soil water? There is a temptation to suggest the oxidation reactions are slowing down because the most reactive spoil

fractions have already oxidized or because the reactive zone is deeper than it used to be. However, the argument is probably specious. We have no evidence that the oxidation rate is slower now than it was in 1974. And if the depth to the reactive zone was a strong variable, the area covered with topsoil would be expected to be different from the untreated area. A more plausible suggestion is that the areas that have been revegetated since 1975 (virtually all of the waste dump except the untreated area of this study) have reduced sulfide mineral dust production to the point where real changes in the soil-water quality are occurring. Dust is an important component of the acid cycle on this mine (Farmer and Richardson 1980).

Regarding the second conclusion, the biological oxygen demand created by roots and microbes in the topsoil apparently has no detectable effect on the oxidation rate of the sulfide minerals. The suggestion that a thin layer of topsoil, and a heavy stand of grass, can reduce or stop the oxidation of waste sulfide minerals no longer appears justifiable.

These conclusions do not reduce the value of a heavy vegetative cover on mining waste piles. The principal value of vegetation on mining wastes has always been to build the edaphic qualities of the spoil and to control surface erosion by water. This work suggests that dust control by vegetation is also important.

The soil-water ionic concentrations measured in this work are many times greater than would be expected for undisturbed conditions. For instance, an adjacent watershed unaffected by mining shows mean streamflow concentrations of copper, iron, and sulfate of 0.10, 0.12, and 4.99 mg/liter, respectively. While streamflow values may not be completely comparable with soil-water values, soil water (both saturated and unsaturated flow) is the basis for perennial streamflow in mountain channels.

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Ceramic cup soil-water samplers were used to determine the soil-water ionic concentrations of copper, iron, and sulfate within an acid spoil dump from 1974 to 1979. Over that time, samples from revegetated and nonrevegetated areas are compared. Differences in sample results cannot be attributed to the effects of revegetation.

KEYWORDS: soil-water quality, soil-water samples, acid mine drainage, revegetation.

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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